Renewable and Sustainable Energy Reviews 40 (2014) 161–170

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A survey on mobile energy storage systems (MESS): Applications, challenges and solutions

Sayed Saeed Hosseini [a], Ali Badri [a,*], Masood Parvania [b]

[a] Faculty of Electrical and Computer Engineering, Shahid Rajaee Teacher Training University, P.O. Box 16788-15811, Tehran, Iran
[b] Department of Electrical and Computer Engineering, University of California, Davis CA, USA

ARTICLE INFO

Article history:
Received 19 August 2013
Received in revised form
14 June 2014
Accepted 17 July 2014

Keywords:
V2G
PEVs
Smart parking lots
MESS
Renewable energy resources
Smart grids

ABSTRACT

The emergence and implementation of advanced smart grid technologies will enable enhanced utilization of Plug-in Electric Vehicles (PEVs) as MESS which can provide system-wide services. With significant penetration of PEVs in the near future, the concept introduced in literatures as Vehicle to Grid (V2G) will be practically possible. The V2G concept eases the integration of renewable energy resources into power system and gives a new force to the inevitable move towards power generation by clean energy resources. Therefore, trends in utilizing energy stored in PEVs will bring undeniable economic and environmental benefits. The V2G aspect has been the field of many research works in the last few years. This paper intends to present a study conducted to reveal the different features of V2G in power system. In this study, V2G applications are investigated from the perspective of power system as well as electric market. In addition, V2G capabilities are discussed to utilize renewable energy resources as secure power sources and to provide ancillary services. Specifically, the paper has detailed the importance of smart parking lots, their opportunities and challenges in relieving V2G difficulties and improving its utilization. In order to clarify different issues, the authors present practical analyses which are results of a loss optimization problem in a residential power grid. From a realistic standpoint, this work has tried to identify the major barriers towards making V2G practical and addresses remarks which will make V2G concept feasible as fast and simply as possible.

Contents

* Corresponding author. Tel.: +98 21 22970029; fax: +98 21 22970033.
E-mail addresses: ali.badri@srttu.edu, a_badri73@yahoo.com (A. Badri).

http://dx.doi.org/10.1016/j.rser.2014.07.183
1364-0321/

1. Introduction

The prospect of vehicles plugging into the electric grids, known as PEVs, is highly supported by undeniable economic and energy-security benefits that result in independence from petroleum and displacement of gasoline by electricity. Interest in PEVs is coming from government, automotive and electric utility industry. The importance of this trend will be strengthened much more with the evolution towards the future smart electric grids. A report issued by US Department of Energy (DOE) highlights the Electric Vehicles (EVs) as one of the 20 criteria for measuring the status of smart-grid deployment and impacts. The EVs have potential to reduce fuel cost, gas consumption, and harmful emissions from both the electricity and transportation sectors [1].

The progression of PEVs creates an inevitable desire for charging them from the grid in large quantities. According to such desire, they have a potential to put an undue strain on power system if they are not supported by smart grid technologies. The PEVs which can plug into the grid include Plug-in Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs). These vehicles tender performance, adaptability and safety and permit convenient and low-cost at-home/public charging [1].

The assessment of the load that PEVs would introduce to the grid and the PEVs role as Distributed Energy Resources (DER) are the most important issues that are highlighted in different research works. In the latter, exploitation of the power stored in the PEVs batteries back to the grid is the main objective. PEVs service as Energy Storage Systems (ESS) is known as V2G concept and has been considered in many research works from different points of view [2–5]. In next 10–20 years, with significant penetration of PEVs enhanced with smart grids capabilities, V2G is expected to provide many economic and environmental benefits for power system [6]. In this way, PEVs could be used as power sources under smart grid environment in terms of controllable loads. Furthermore, V2G services as ESS could also help to overcome difficulties associated with the intermittent nature of renewable energy resources such as wind and solar energy [1]. Moreover, renewable energy resources would reduce emission from power and transportation sectors by supplying PEVs. Accordingly the integration of renewable energy resources with V2G development gives a new path to clean energy generation in different scales and sectors of power system, especially in distribution levels and micro-grids. This benefit is so remarkable and many research works have highlighted the application of V2G for integration with renewable energy resources [1–4].

This paper presents a comprehensive review conducted in order to reveal the different aspects of V2G in electrical power systems. This study focuses on V2G applications from major market stakeholders' (PEVs manufacturers, customers, and power system agents) perspectives as well as V2G services in electricity markets. V2G aspects are classified based on the stakeholders' concerns and interests in order to make V2G practical. The classification is performed with the intention of presenting an accurate and detailed outlook for V2G applications. In addition, V2G capabilities in terms of ESS are discussed as a solution to overcome difficulties related to utilization of renewable energy resources. The importance of parking lots and their qualification to bring about a confident and proper trend in utilizing V2G are also analyzed. Furthermore, different concrete analyses are conducted as a consequence of a loss optimization problem in a residential distribution grid to give an exact figure of some issues. The optimization problem results in a coordinated charging scenario for PEVs which minimizes the grid losses. On the other hand, with respect to coordinated charging strategy, uncoordinated charging is considered which means charging PEVs right after arriving home in the evening. Moreover, the problem is developed in order to consider V2G approach and smart parking lot facilities. This work presents applicable solutions which can make V2G concept feasible as fast and simply as possible.

The rest of this paper is organized as follows. Section 2 discusses opportunities and challenges toward V2G system specifically from major stakeholders' perspective. Section 3 introduces smart parking lots as a solution for real-world implementation of V2G concept. Section 4 provides the classification of V2G applications in power system and electricity markets. Section 5 addresses the issues related to the integration of renewable energy resources with V2G system. Finally, Section 6 presents the concluding remarks.

2. V2G concept

Conventional thinking on PEVs reflects the estimation that these devices would be added as a load to power grids for charging during evening until next day morning hours. This inference ignores a significant opportunity that mobile energy storage systems which are connected to the grid can be used to provide valuable grid services as V2G system. There are two beliefs regarding the PEVs integration into power grids:

- conservative belief—the belief that the presence of PEVs in power grids is a factor to postpone the upgrading, modernization and enhancement of power systems [1],
- progressive belief—the belief that PEVs represent a historic business opportunity for the electric utility and disrupt the supply and demand correlation by realizing a DER [1].

The first belief does not have many followers in the power industry. The reason is that it leaves PEVs as an undesirable load for System Operator (SO) and takes away any chances of utilizing PEVs as providers of power system services. Furthermore, the conservative belief decreases incentives and facilities which may have influence on customer desires to purchase a PEV. On the other hand, progressive belief fulfils the vehicle owners of making profit from selling the stored energy in their PEVs batteries.

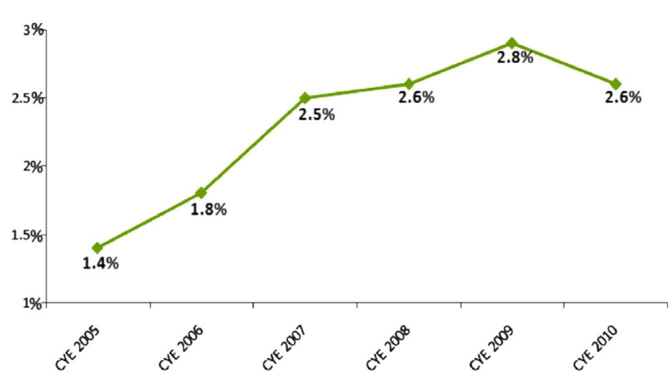

Fig. 1. HEV share of U.S. light vehicle retail registrations [9].

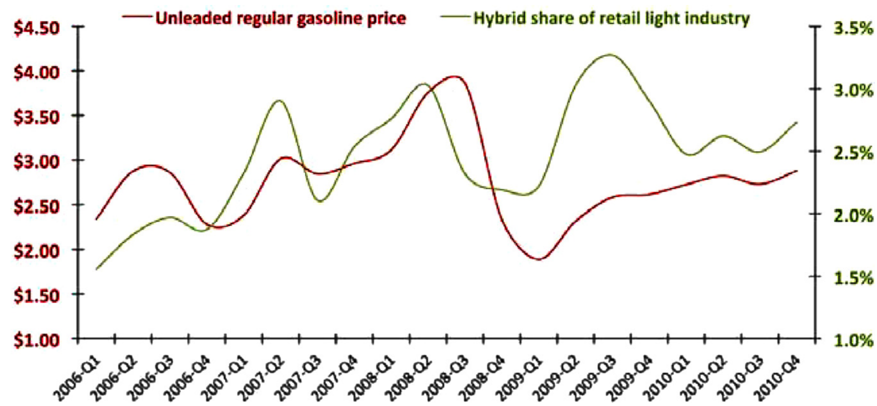

Fig. 2. U.S. HEV market share and gasoline prices [9].

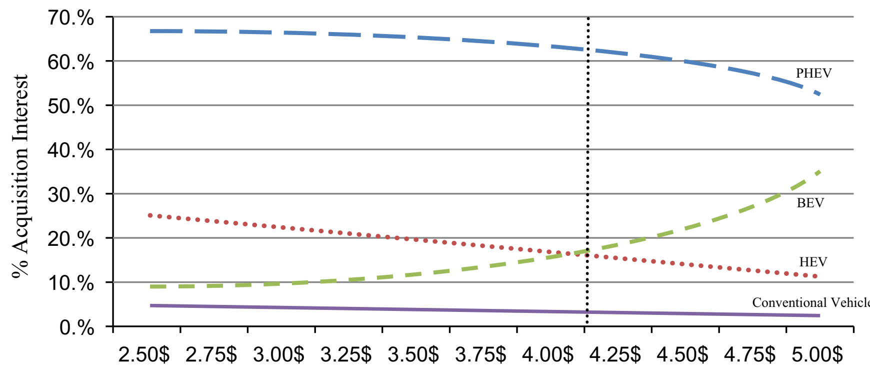

Fig. 3. Influence of gas price on vehicle acquisition preferences [10].

In addition, it offsets PEV's high purchase and maintenance costs and reduces money payback period. On the supply side, the second belief delivers benefits of procuring V2G services for SO. For instance, V2G interfaces can manage stresses on the grid such as peak demand and consequently pass savings onto consumers [7]. However making this mutual satisfaction feasible requires establishing awareness in customers, providing appropriate incentives for vehicle manufacturers and upgrading the power grid infrastructures [1]. In the following, authors investigate the V2G challenges from main stakeholders' viewpoints.

2.1. Vehicle manufacturers challenges

In the first step, making V2G concept practical depends on commercializing PEVs and developing the battery storage and power electronic devices [4]. Since providing the grid services by PEVs requires the aggregation of a large number of vehicles, PEVs commercialization is very important for V2G development. For example, U.S. Freedom Car and Vehicle Technologies (FCVT) is evaluating PEVs technology and searching for the most technical barriers to commercialize PEVs [8]. Among these difficulties, battery degradation is the most significant one for commercializing PEVs. Data provided by manufacturers about battery life cycle and performance become more critical, specifically when V2G applications are also considered. The reason is that PEVs are required to be more frequently charged and discharged in order to provide grid services through V2G. In addition, the manufacturers should utilize battery technology which is adaptable to frequent charging cycles. These issues associated with V2G applications challenge PEVs manufacturers more than before.

Overcoming these challenges is complicated and depends on various issues that some of them are not directly related to the vehicle technologies and development. Fuel prices and fickle nature of customer preferences are the most important factors among these issues. When fuel prices rise, customers tend to buy the EVs and when fuel prices drop EVs are less popular [1]. Fig. 1 shows that U.S. Hybrid Electric Vehicles (HEVs) market share dipped in 2010 which can be attributed to the lower gasoline prices shown in Fig. 2 [9].

Influence of prospective gas prices on vehicle acquisition interest is shown in Fig. 3. The black dashed line highlights the tendency to switch from PHEVs to BEVs at 4$/gal [10]. As shown, decrease in gas prices leads to more utilization of HEV and PHEV with respect to BEV. Furthermore, the growing availability of fuel-efficient nameplates with potential to reduce fuel consumption and less fuel-efficient vehicles which are still compliant with current Corporate Average Fuel Economy (CAFE) standards is effective for EVs acceptance and makes up for their uncertainty in market share[1,9–12]. Less fuel-efficient nameplates are vehicles with minimum requirements for CO_2 emission and CAFE standards compared to fuel-efficient cars with high-level standards. The U.S. DOE forecasts, presented in the Annual Energy Outlook (published in February 2012), are very conservative about EVs market penetration contrary to the Electrical Power Research Institute (EPRI) and Natural Resources Defense Council (NRDC) predictions. EPRI and NRDC used a customer choice model to estimate market penetration rates [13].

2.2. Customers challenges

PEV owners are not still completely convinced to allow SO to use their vehicles for providing system services. Battery degradation due to more frequent charge/discharge cycles is the major reason for this doubt. In fact, a significant gap exists between customer expectations of PEVs capabilities and what a PEV can deliver today. Customers generally feel that automakers should

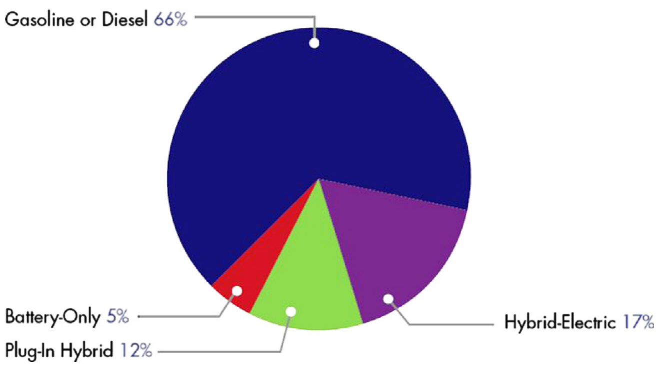

Fig. 4. Type of next new vehicles based on the purchase likelihood scores [15].

Table 1
Classification of various charging levels and capabilities [1].

Characteristic	Normal charger		Rapid charger
	Level 1	Level 2	Level 3
Voltage	110–120	208–240	480
Charge power (kW)	1.8–1.9	≤ 14.4	30–250
Estimated charge time	10–20 h	3–8 h	< 30 min
Estimated price	~US$1000	US$500–3000	US$17,500–50,000

offer PEVs that are capable of going farther with less charge time and cheaper price than before [1]. Additionally, other customer concerns for buying a PEV may include [10]

- existence of charging stations near PEVs owners,
- duration of a full charging time especially in an emergency situation,
- PEVs prices compared with the prices of gas-fueled vehicles, and
- effects of PEVs charging types on customers' electricity bills.

The evaluation of PEVs prices and their payback period exert a deep influence on customers' satisfaction. PEVs prices and maintenance are more than those of mass-produced gasoline or diesel vehicles. Thus, some manufacturers lease PEVs to minimize the maintenance costs and potential risks. In addition, other difficulties related to the batteries such as the need for owners to replace large, heavy and costly batteries every few years are effective on their approval. Accordingly battery producers are expected to produce an estimated 1.51 million battery units in 2015, almost nine times greater than current production rate [14]. Fig. 4 shows the respondents' purchase likelihood scores after reviewing vehicle information conducted by the U.S. southern company [15]. In Fig. 4 there is still a large tendency for respondents to purchase gas-fueled vehicles, while the interest to have BEVs is low. The fact is that no more than 2–4% of population in any country would have their expectation of PEVs met today [1].

2.3. Power system challenges

Development of grid infrastructures should be considered at the same time while commercializing PEVs. Residential homes, government facilities and business centers must have adequate electrical capacity for vehicle charging. In this regard, special outlet hookups or upgrades may be required. Furthermore, the need for higher voltage levels in distribution systems for public fast charging stations (which takes a PEV approximately less than 20 min to charge) is another grid technical issue. There are already three charger levels for PEVs batteries which are shown in Table 1.

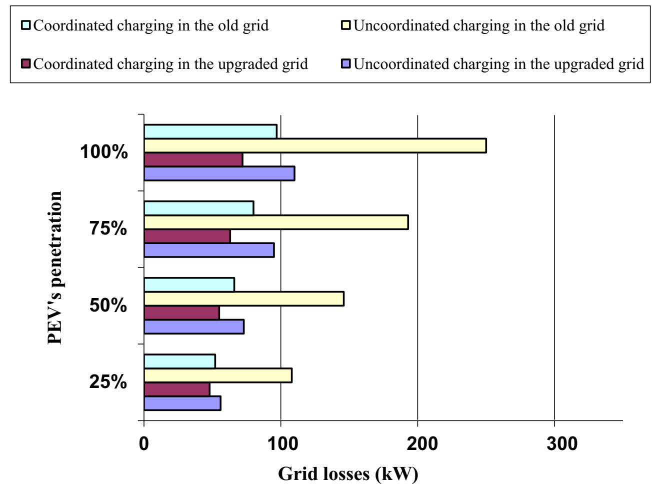

Fig. 5. Residential grid losses for different charging scenarios in the upgraded and old grids.

Among these levels, level 2 is more preferable due to its characteristics such as duration of charging time, the price and impacts on batteries' life. Although fast charging stations (level 3) may be superior, their utilization is limited due to their high costs which are about 10 times more expensive than those of level 2 [1].

In addition, PEVs need a communication and control infrastructure for fast and accurate responses to signals received from a central grid operator. Communications facilitate aggregating individual PEVs into a single controllable V2G system for providing effective grid services [16]. Such requirements highlight the importance of smart grid technologies to enable V2G applications. V2G concept can be realized via PEVs management and scheduling in a dynamic power grid that would be feasible under smart grid infrastructures [1,6]. The smart grid development prepares more tools, options and players that employ various technology standards, practices, and policies for the successful operation of V2G services. For instance, V2G can be promoted to a useful role for balancing energy in power system under Demand Response (DR) practices which are recognized as a key application of smart grids [16]. Additionally, in a high-tech smart grid, PEVs owners can participate in electricity markets using smart phones which are capable of real-time communication between owners and the market operator [14].

In addition, smart grid development necessitates upgrading power grid infrastructures even without considering the V2G concept. This prerequisite benefits both SO and PEVs owners. For instance, modern girds provide PEVs owners with new facilities such as fast charging, special outlets for charging, etc. Moreover, upgraded grids cause power system losses related to excess load from PEVs energy requirements to decrease significantly. This advantage could be observed by a simple evaluation of coordinated and uncoordinated charging scenarios in both upgraded and old grids. Here, the old and substandard grid is modeled on a grid with a defective conductor which has a resistance a little more than that of the upgraded grid's conductor. As shown in Fig. 5, coordinated charging scenario in the old grid approximately has the same result as that of the uncoordinated charging scenario in the upgraded grid. Moreover, the uncoordinated charging strategy in the old grid results in large losses, twice that of the related amount in the upgraded grid. This outcome fortifies the importance of smart grid development even more because the majority of PEVs owners prefer to charge their vehicles after arriving home, known as uncoordinated charging scenario. It should be mentioned that the residential grid is a radial grid with 48 consumers that each one has a connection to a PEV with a

Table 2
Summary of challenges and solutions for V2G realization.Notes:

V2G approach		
Stakeholders	Challenges	Solutions
Vehicle manufacturer	Commercializing PEVs	Increasing customer preferences
	PEVs technology	Investment and research
	Development of battery storge	Government supports
Customers	PEVs prices	Mass production and incentives
	Battery degradation	Development of technology
	Emergency situations	Smart grids
	Infrastructural support	Government supports
Power system	Grid infrastructure	Development and modernization
	Dynamic economic market	[a]Intelligent communication structure
[b]Unforeseen sides	Fuel prices	[c]Government policies and support
	Fuel-efficient engines with CAFE	Development of technology

[a] Reliance upon development of smart grids.
[b] Not a participant but really effective and sensible.
[c] Policies for avoiding dependence on fuel such as utilizing large-scale renewable energy resources.

maximum storage capacity of 10 kWh. Monte Carlo simulation is used for applying randomly chosen PEVs to the consumers' load profiles and the optimization problem is solved using convex optimization package CVX [17].

2.4. Collaboration between stakeholders

The challenges mentioned above for V2G realization are summarized in Table 2. Addressing these challenges and achieving the V2G concept require collaboration between various stakeholders. In fact, the amount of power that PEVs could deliver back to the grid for V2G application depends on:

- size of the battery pack,
- the state of charge (SOC) when a vehicle is plugged-in,
- the capacity of the plug circuit,
- battery life cycle and degradation,
- the maximum battery charge and discharge, and
- the available capacity of PEVs electric power (because it is possible that there is a large amount of PEVs storage in grid which is not available).

Accordingly, increasing the V2G capacity relies not only on development of grid infrastructures and vehicle technologies but also on customer behaviors that in turn express the importance of cooperation between the participants. As a solution, V2G would be technically feasible with suitable evaluation of projects in all fields. These projects vary according to the field they focus on: some organizing to find methods to maximize PEVs storage in order to increase the quantity of renewable energy resources, and some to find a more integrated smart grid structure [6].

It should be noted that due to differences between power system structures among countries, it is possible that V2G would not be beneficial for some power systems. For example a study in [18] concludes that, due to limited enhanced grid technologies, employing V2G in German power system is not as useful as in U.S. power system. In such cases, the V2G concept is neglected and PEVs can be first used in terms of unidirectional storage for grid services instead of bidirectional ones. The unidirectional service needs few additional communication infrastructures and is simple for contribution to the market. Moreover, such service is more acceptable from customer view and increases power system utilization experience before V2G emergence. However, the vision of PEVs as providers of grid services is generally considered as a bidirectional source in terms of V2G system [1].

Therefore, transition to the V2G concept includes different barriers that are not just technical. Customer behaviors and economic incentives as well as cultural and social values and business exercises related to the resistance against infrastructural changes are among non-technical obstacles towards realization of the V2G concept [1–3]. As the most important issue, government supports are undeniable to overcome all challenges. For instance, the U.S. government is going to prepare the following incentives within next couple of years [1,19]:

- by 2015 puts 1 million PHEVs on the road, based on 2011 DOE report, that can get up to 150 miles per gallon;
- by 2014 makes PHEVs cost competitive and by 2016, ready for volume production commercialization;
- by 2014 reduces the production cost of market-ready, high-energy, and high-power batteries by 70% of 2009 costs;
- provides a $7000 tax credit for purchasing advanced technology vehicles and convert tax credits to create a market as well as show government leadership in purchasing highly efficient cars.

3. Smart parking lots: opportunities and challenges

The emergence of smart parking lots in power systems will help V2G concept to be more successful [20–25]. Smart parking lots are special parking/charging places for PEVs that are equipped with necessary communication infrastructures and intelligent devices for V2G services. They can be equipped with V2G technologies and smart grid necessities easier and faster than individual houses. Smart parking lots reduce the need for massive communication platforms and expensive fast charging facilities in homes for fast response to grid services. This concept is appropriate due to PEVs faster development than smart grid technologies in the context of power systems structure. In addition, smart parking lots help V2G to be more feasible due to their criteria, incentives and facilities because owner behaviors are very stochastic and unpredictable especially in terms of at-home charging. They can solve the customer uncertainty about the infrastructural support for charging facilities as an important concern [20,21].

Moreover, constructing parking lots in low-load areas of grid or in areas with high capacity lines and transformers could help power system to bear the excess load from PEVs energy requirements. Therefore, parking lots could be effective even if V2G concept would not be considered [20]. As an important advantage, parking lots could be equipped with renewable energy resources, specifically solar panels, in order to provide PEVs energy requirements. As a result of this, SO not only generates lower amount of energy to charge PEVs batteries but also utilizes these batteries to prepare V2G services without concerning much about recharging them. In order to make this approach more clear, a parking lot is located in the residential grid where its roof is equipped with solar panels that produce 40% of the energy storage for all PEVs batteries. As seen in Fig. 6, coordinated charging scenario in parking lot leads to a significant reduction in grid losses in comparison with at-home charging strategies including V2G approach. Therefore, the integration of smart parking lots aspect with renewable energy resources can be considered as an efficient option as well [20].

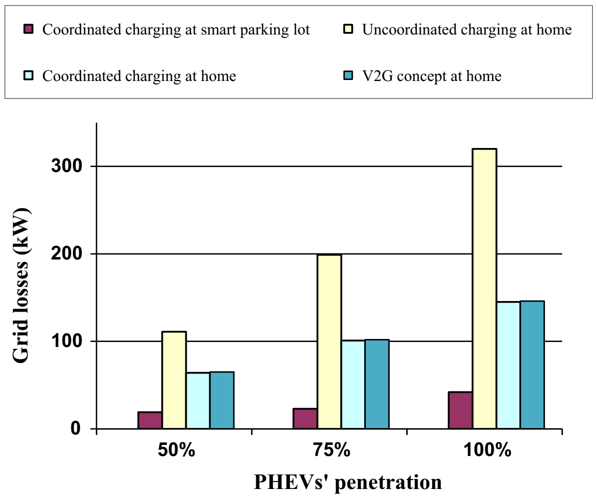

Fig. 6. Residential grid losses for different charging scenarios including V2G at home and coordinated charging scenario at smart parking lot.

It can be seen that V2G has not made a notable decrease in grid losses compared to coordinated charging scenario at home. The reason is that the problem assumes that PEVs arrive home in the evening with empty batteries and cannot be charged during the day. Thus they do not have energy to be used by SO in peak hours. This raises an important remark regarding the utilization of V2G system which is the need for a thorough assessment of V2G potentials before any infrastructural investment. Development of public charging stations in workplaces can be considered as a solution to such challenges. PEVs owners can charge their vehicles when go to work in the morning with the result that they have available energy for V2G services in the evening [17,21]. Generally, smart parking lots can prepare opportunities to take fast and practical advantages of V2G applications. A typical structure of a smart parking lot is shown in Fig. 7 [25]. It should be pointed out that the capacity of PEVs batteries is considered to be 16kW in here, as it is in mid-size sedans like Chevrolet Volt in order to have more sensible results of smart parking lot problem.

Additionally, parking lots can serve fast and safe charging that has a strong influence on customer satisfaction. Fast charging draws strong interest among customers and facilitates a greater adaptation to PEVs technology. Consequently, smart parking lots can increase customer's interest to PEVs. The various issues associated with smart parking lots are listed below:

1. Charging scheduling for competition in power market in order to achieve maximum profit or handling system problems such as peak shifting and load curtailment.
2. Defining incentives to fulfill PEVs owners' expectations such as providing parking lots with protection systems against network transient and failure that damage PEVs batteries. In addition, preparing charging stations with fast charging facilities whereas long time duration for full charge brings about high preferences for at-home charging.
3. Economic incentives such as battery swapping which substitutes a dead battery for a freshly charged one. This advantage could reduce the cost of the battery and remove the concern about charging time.

It is worth mentioning that at-home charging concept is still regarded because consumer charging preferences expect to charge PEVs primarily at home [10]. For instance, the author of [2] has considered that the best position for providing V2G is when PEVs are parked at home. Therefore, interest in public charging is very important for success of smart parking lots approach. Educating

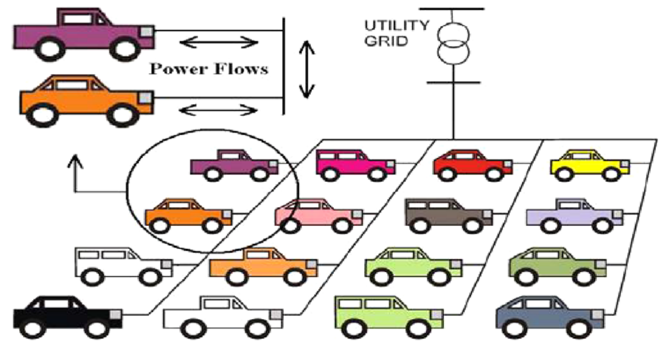

Fig. 7. Typical structure of a parking lot for V2G system [25].

and informing customers regarding available parking stations will be necessary to promote public charging reputation, especially for those who may not have the availability of at-home charging. It will also be desirable for those who are reluctant for buying a PEV due to its necessity for at-home charging devices such as electrical outlet types (i.e., voltage), wiring requirements, etc. [16].

On the other hand, parking lots are limited due to some issues concerning their utilization. An important unanswered question is about who pays for recharging infrastructures in public spaces [20]. The business case for investing in these improvements is weak because of high costs and initial consumer preferences for at-home charging. Battery swapping and fast charging costs would add to the cost of a parking lot infrastructure. Furthermore, battery swapping makes considerable challenges for PEVs manufacture while fast charging results in significant troubles such as battery life degradation, safety problem related to high-voltage circuits and stress on regional power grid [14,26]. However, these facilities are so remarkable for customers' deep pleasure. For instance, a discharged battery could be substituted with a charged one in less than 2 min without getting out of the car [14]. According to all limitations on smart parking lots, it is undeniable that this approach could be so useful in existing power grids with regard toV2G outlook [20]. Smart parking lots have an effective role in the V2G concept development.

4. Classification of the V2G applications

Based on previous studies and technical reports released by different entities, the authors have provided a classification for V2G applications. Accordingly, these practical usages may be classified into two general categories: power system and power market applications. Nevertheless, V2G applications in power market require some prerequisites that are addressed below.

4.1. Power system applications

Attention to available capacity of PEVs batteries and grid scale and characteristics, V2G applications could be considered from various aspects, categorized as below.

4.1.1. V2G as a virtual power plant (VPP)

The capacity of PEVs fleets can be utilized in power system as a virtual power plant (VPP) [27–29]. This approach can be generally used for evaluating V2G capacity together with generation and transmission sectors. Minimizing energy cost and pollution with focus on the integration of large-scale renewable energy resources are the most important issues from this point of view [5,30,31]. VPP can be evaluated to balance power supply and demand, decrease the generation of power plants and replace the costly generation units especially in peak periods [18].

In this application, PEVs energy dispatch is not accounted. Instead, total available capacity of batteries is taken into account for preparing possible grid services. In fact, VPP concept is considered due to small and straggly capacity of PEVs. From this point of view, this application can be used in all power system levels along with other existing sources. Accordingly VPP concept can be deemed in microgrids and isolated islands for examining power resources, especially as a backup for poor and intermittent nature of renewable energy resources.

4.1.2. V2G for power system security enhancement

The optimal placement of PEVs is determined for more secure power system utilization that has been less concerned. Obviously, this approach is considered in distribution sectors and microgrids because of the variety of grid types such as radial or ring grids with different voltage levels. V2G application in these sectors is advantageous to various issues such as Outage Management (OM), system security and emergency conditions. Furthermore, this application raises the importance of optimal placement of smart parking lots in order to prepare V2G and supply PEVs energy requirements [22–24,32]. The optimal placement can be performed to develop parking lots in possible MV voltage levels of distribution systems. This in turn reduces the need for fast-charging infrastructural requirements with respect to PEVs owners' tendency to recharge their vehicles in 2 h or less [18]. Therefore, customer priorities need to be satisfied in PEVs optimal placement for V2G services and this could be possible by parking lots development [21].

4.1.3. V2G for microgrids implementation

Application of distributed energy resources, Combined Heat and Power (CHP) systems and distributed energy storage systems are making microgrids and active distribution systems realizable. Most noteworthy energy recourses in microgrids are renewable energy resources and thus availability of PEVs would mitigate their variability. Additionally, V2G can be noticed for services such as voltage control and frequency regulation in microgrids and autonomous islands [33]. PEVs can bring about a flexible resource for efficient microgrids operation through innovative charging strategies. V2G system development can create an advanced Demand Side Management (DSM) method in microgrids [33–35].

4.1.4. Utilizing as V2B/V2H

Development of PEVs technologies at customer sites can be utilized to meet demand in peak hours and supply energy in commercial and residential buildings as Vehicle to Building concept (V2B) [24] and in houses as Vehicle to House (V2H) concept [36]. This idea is strengthened with strong interest in public charging locations such as workplaces, gas stations and shopping centers/malls [24]. In other words, parking lots equipped with bidirectional chargers and controllers make it possible to integrate PEVs electrical energy into building load curves [10].

4.2. Electricity market applications

In addition to common V2G design considerations, requirements for a proper market design for V2G participation should be taken into account. Making profit from selling PEVs' stored energy in electricity markets is targeted by PEVs owners as a key stakeholder. Such participation would make a big incentive for owners and could be settled in retail and wholesale markets [20–24,37]. The owners can not only make revenue by allowing market operator to use their PEVs for V2G services but also get discount just by charging their vehicles under alternative charging plans. These plans represent savings in consumers' bills when they charge PEVs in off-peak periods or only at night [15]. Moreover, PEVs may be interpreted as pioneers in electricity market in terms of restructuring market rules and providing liberalization in demand-side market. In this regard V2G applications and requirements are explained below.

4.2.1. V2G to provide ancillary services

The importance of PEVs participation in electricity markets is fortified with the growth of tendency to utilize renewable energy resources in conjunction with a flexible and reliable energy supply for regulation and reserve [18]. The large number of available PEVs batteries is vital for fast-regulation and short-duration market applications. Furthermore, PEVs fleets would make a greater competition in electricity markets and have a strong impact on all participants' acquiescence [18]. The most promising markets for PEVs are the ancillary service markets. Two specific ancillary services in wholesale electricity markets in which PEVs can play an important role are regulation and spinning reserve markets [1]. Frequency regulation is the most practical market for V2G, and development of fast charging infrastructures makes it more feasible [27,38,39]. PEVs can provide both unidirectional and bidirectional ancillary services. A unidirectional PEV is limited to bidding for regulation and spinning reserve in ancillary markets. It cannot deliver the energy stored in its battery to the grid. Therefore, a bidirectional PEV permanently introduced as V2G is considered for providing grid services [38,40]. V2G through an advanced DSM can technically lead to balance power in smart grid structure [18].

In addition, V2G capabilities can be considered for load management and peak load reduction as an alternative to costly generation units [17,20,21,33]. For instance, [41] concludes that V2G contribution in peak hours is more acceptable than regulation and reserve markets. Some other studies do not suggest V2G utilization in peak hours, because these services are needed for just a few hours a year which is not worthwhile from economic aspects [1]. However, V2G services would have more impacts in peak periods in small power grids such as microgrids [20,21,33,35]. This can be examined in the residential power grid model as a result of an assumption that PEVs owners fully charge their vehicles in public charging stations at work, as mentioned before. Since the battery capacity is equally consumed by a travel pattern between home and work, a PEV has 50% energy when arriving home in the evening. It is a reliable assumption due to fast growth of smart parking lots in commercial and industrial places, universities, etc. As shown in Fig. 8, V2G concept successfully reduces peak hours' losses by half. V2G system is effectively

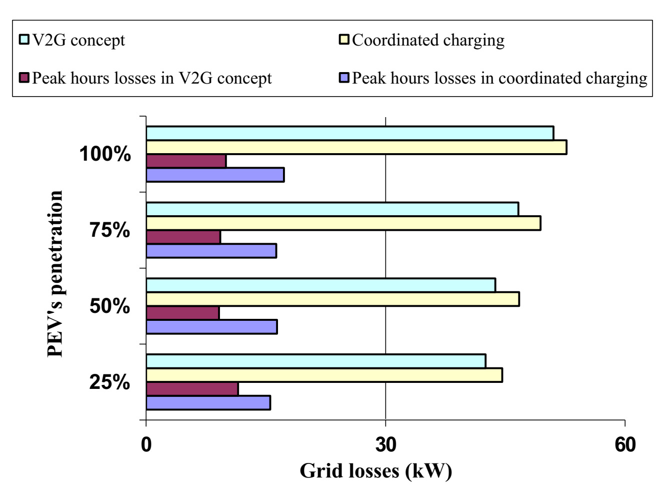

Fig. 8. Residential grid losses for different charging scenarios and V2G concept.

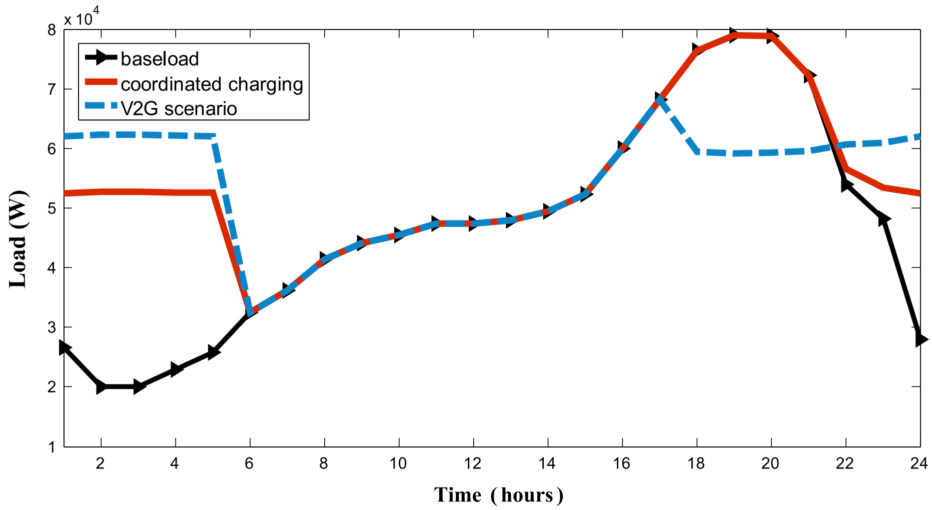

Fig. 9. Load profile for coordinated charging scenario and V2G concept.

employed in comparison with coordinated charging scenario and also results shown in Fig. 6 [17].

On the other hand, by utilizing V2G, SO needs more energy to fully charge PEVs batteries at off-peak periods primarily during night before the next travel in the morning. However, it can be seen that V2G services not only do not increase total grid losses but also decrease it. This fact proves the effective role of V2G in facilitating power system operation especially at peak hours. Fig. 9 shows how V2G efficiently shifts the load profile at peak hours for PEVs' penetration of 100%.

Additionally, V2G utilization would be more attractive for energy management and load shifting in large consumers. V2G can help large consumers to reduce their costs, serve their critical loads during a disruption, manage the risk, and focus on utilizing renewable energy resources [42]. Furthermore, by preparing fast charging facilities, large consumers would be able to provide grid services as well [24].

It should be noted that the best V2G operation strategy is achieved when the PEVs fleets are treated as resources during discharge periods. PEVs would require a controllable charging strategy and a proper travel pattern for V2G applications [31,43–45]. The costs of enabling V2G services in electricity markets should also be noted. These costs include both the PEVs fleets' costs and power system costs. PEVs fleets' costs consist of additional cost to enable V2G option on vehicles as well as cost of battery degradation. The power system costs contain cost of communication and control infrastructures required to capture PEVs flexibility [1].

4.2.2. Requirements for V2G participation in the market

For accelerating V2G participation in electricity markets, the following issues should be taken into consideration.

a) PEVs aggregation
Development and design of an efficient aggregation framework for optimal utilization of PEVs batteries is crucial in favor of V2G applications in wholesale markets. This aggregation structure would realize optimal charging strategies for PEVs including V2G. The importance of design of an aggregator for providing market services can be observed from various aspects [46,47]:
- the unexpected and different starts and durations of charging time between PEVs,
- the SOC variations between PEVs while plugging-in,
- the travel patterns of PEVs and the owners' different behaviors and desires,
- targeted scheduling of PEVs based on market requirements, bids and power system conditions.

The PEVs aggregator could be a Distribution System Operator (DSO), a retailer or an independent market participant such as parking lot owners, who earn profit from selling off services to grid. Additionally, the aggregator is responsible for meeting PEVs owners' requirements based on their personal preferences [1,32,46]. One of the important roles of the aggregator could be the coordinated operation of PEVs fleets and renewable energy resources. This function would be of greater importance in microgrids. Moreover, the aggregator would be responsible for monitoring, control, and charging scheduling of PEVs.

b) Smart parking lots
PEVs form a large population of MESS and thus an intelligent and versatile communication infrastructure is required for coordination between them and DSO. Overcoming this challenge and creating an efficient dialog with electricity market could be realized by placement of PEVs in smart parking lots [1,24]. Smart parking lots would also ease PEVs management through the aggregators.

5. Integration with renewable energy resources

PEVs do not produce emission and would help reducing the carbon footprint of transportation system. In fact, environmental issues are effective in increasing interests in PEVs. An analysis by the U.S. Environmental Protection Agency (EPA) shows that if PEVs had a 30% market share by 2025 and maintained it until 2050 they could reduce emission up to 11,000 million metric tons of CO_2 until 2050 [48,49].

The reduced amount of emission by PEVs deeply depends on energy sources utilized to supply the associated power. Therefore providing PEVs energy by clean energy resources, such as wind and solar, would assist in reaching environmental benefits. This necessity is strengthened with policy recommendations built upon energy independence, fuel crisis and security. For instance, U.S. government has set a national goal of generating 80% of electricity from clean energy resources by 2035 [7]. However, an analysis conducted by [48] shows that providing PEVs energy from conventional power plants produces less emission than that of

gasoline vehicles. Even if PEVs utilization does not reduce Green-House Gases (GHG), it would take away emission from populated urban areas.

Furthermore, the intermittent nature of wind and solar energy resources challenges power system operation and makes them unsecure especially as base-load resources. As a promising solution to alleviate the variability of renewable energy resources, ESS and backup generation systems have been suggested though they add capital costs. PEVs have potential to resolve the need for costly ESS in terms of MESS through V2G development. This could be possible by charging scheduling of PEVs to store renewable energy generation when it is not needed, and supply the stored energy to SO when it is of greater operational value. Coordinated operation of PEVs as MESS and renewable energy resources is expected to be one of the promising applications of PEVs in near future. This application would affect both the electrical power and transportation landscapes and would provide a sustainable strategy for renewable energy integration.

The integration of renewable energy resources with V2G could be generally outlined in two perspectives that include large scale generation such as large wind turbines and small scale generation such as rooftop solar panels [7]. In large-scale application, the aim of integration is to reduce the additional investment of conventional units or phase out high polluted power sources like coal plants. Economic and environmental issues are the most important concerns in this application [1,28,50–52].

Usually large renewable energy resources are located far from demand centers and would require massive investments to develop and upgrade transmissions systems. Therefore the second concept discusses the integration of renewable energy resources as Distributed Generation (DG) with PEVs in distribution systems, especially in microgrids [33–35,45,53]. With a sufficient amount of this integration, distribution grids may be developed to act as a set of interconnected microgrids that have capabilities to operate in islanded mode [46]. Consequently, it is envisioned that the second application would be more attractive and demonstrate the most promising benefit of V2G systems albeit in the initial stages.

6. Conclusion

PEVs interconnect the transportation and electricity sectors and provide a new opportunity for smart grids development. With development of smart grids and employing PEVs as MESS, V2G concept would be more strengthened and desirable. From this point of view, PEVs could be more attractive for customers and utilities and lead to vehicles owners and SO satisfaction. On the other hand, due to the existing challenges in customer side for buying a PEV, in manufacture side for commercializing PEVs, and in power system side for supplying these massive loads, governmental supports are crucial. The governmental supports through tariffs and incentives would speed up development of PEVs technologies. In addition, governments may support required power system infrastructure. This would be a key factor in fulfilling the aspirations of widespread electrification of vehicles as an important factor towards V2G systems and their benefits.

This paper has presented a comprehensive study of V2G from different perspectives and classifications. The authors have concentrated on required and essential fields and options with actual models to put V2G concept in practice. Due to the faster growth of PEVs than smart grids and the need for intelligent infrastructures for V2G services, the paper highlights development of smart parking lots. Smart parking lots can be considered as the most promising approach to making V2G practical. They have a variety of significant aspects that have been less discussed and can realize the theoretical benefits of V2G. Furthermore, the paper has noticed the importance of proper design of an aggregator for providing ancillary services. The necessity of an optimal aggregation framework is undeniable for making V2G concept more practical.

The next step in PEVs study could be a thorough investigation about employing PEVs as load. Opportunities and challenges related to emerging PEVs fleets could be fully understood if these controllable instruments are considered as loads and MESS as well.

References

[1] Hosseini SS, Badri A, Parvania M. The plug-in electric vehicles for power system applications: the vehicle to grid (V2G) concept. In: Proceedings of the IEEE conference on sustainable transportation systems, 2012. p. 1253–8.
[2] Peterson SB, Whitacre JF, Apt J. The economics of using plug-in hybrid electric vehicle battery packs for grid storage. J Power Sources 2010;195:2377–84.
[3] Sovacool BK, Hirsh RF. Beyond batteries: an examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition. Energy Policy 2009;37:1095–103.
[4] Quinn C, Zimmerle D, Bradley TH. The effect of communication architecture on the availability, reliability, and economics of plug-in hybrid electric vehicle-to-grid ancillary services. J Power Sources 2010;195:1500–9.
[5] Saber AY, Venayagamoorthy GK. Intelligent unit commitment with vehicle-to-grid—a cost-emission optimization. J Power Sources 2010;195:895–911.
[6] Accenture's Study. Betting on science: disruptive technologies in transport fuels, ⟨http://www.accenture.com/us-en/Pages/insight-disruptive-technologies-transport-fuel-summary.aspx⟩; 2009.
[7] U.S. Department of Energy (DOE). A policy framework for the 21st century grid: enabling our secure energy future, ⟨http://energy.gov/oe/downloads/policy-framework-21st-century-grid-enabling-our-secure-energy-future⟩; June 2011.
[8] Argonne National Laboratory. Plug-ins: the future for hybrid electric vehicle, ⟨http://www.transportation.anl.gov/phev/index.html⟩; 2012.
[9] Polk View. U.S. hybrid market share suffers, expected to rebound, ⟨https://www.polk.com/knowledge/polk_views/us_hybrid_market_share_suffers_expected_to_rebound⟩; April 2011.
[10] Energy Power Research Institue (EPRI). Characterizing consumers' interest in and infrastructure expectations for electric vehicles: research design and survey results, ⟨http://www.epri.com/⟩; May 2010.
[11] U.S. Energy Informaion Administration (EIA). Annual energy outlook 2013 with projection to 2040, ⟨www.eia.gov/forecasts/aeo⟩; April 2013.
[12] U.S. Environmental Protection Agency (EPA). Greenhouse gas emissions from the U.S. transportation sector: 1990–2003, ⟨http://www.epa.gov/otaq/climate/basicinfo.htm⟩; March 2006.
[13] U.S. Department of Energy (DOE). 2010 smart grid system report, ⟨http://energy.gov/oe/downloads/2010-smart-grid-system-report-february-2012⟩; February 2012.
[14] Deloitte.Unplugged: electric vehicle realities versus consumer expectations, ⟨http://www.deloitte.com/view/en_GX/global/search/index.htm?searchKeywordsField=Unplugged%3A+Electric+vehicle+realities+versus+consumer+expectations⟩; September 2011.
[15] Energy Power Research Institute (EPRI). Southern company electric vehicle survey: consumer expectations for electric vehicles, ⟨http://www.epri.com/⟩; October 2011.
[16] International Electrotechnical Commission (IEC). Grid integration of large-capacity renewable energy sources and use of large-capacity electrical energy storage, ⟨http://www.iec.ch/whitepaper/gridintegration/?ref=extfooter⟩; October 2012.
[17] Hosseini SS, Badri A. Optimal charging strategy of plug-in electric vehicles (PEVs) for the system indices improvement in smart distribution grids [M.Sc. dissertation]. Tehran, Iran: Shahid Rajaee University; 2013.
[18] Dallinger D, Krampe D, Wietschel M. Vehicle-to-grid regulation reserves based on a dynamic simulation of mobility behavior. IEEE Trans Smart Grid 2011;2(2):302–13.
[19] Energy Speech. Barack Obama and Joe Biden: new energy for America, ⟨http://www.barackobama.com⟩; 2011.
[20] Hosseini SS, Badri A, Parvania M. Smart parking lot to minimize residential grid losses based on customer priorities. In: Proceedings of the IEEE international conference on power, energy and control (ICPEC), 2013. p. 728–32.
[21] Hosseini SS, Badri A, Parvania M. Smart parking lot to minimize residential grid losses considering V2G concept: a customer base approach. In: Proceedings of the 9th international energy conference, 2013. p. 1–10.
[22] Saber AY, Venayagamoorthy GK. Optimization of vehicle-to-grid scheduling in constrained parking lots. In: Proceedings of the IEEE Power and Energy Society General Meeting, 2009. p. 1–8.
[23] Saber AY, Venayagamoorthy GK. Unit commitment with vehicle-to-grid using particle swarm optimization. In: Proceedings of the IEEE conference on Power Tech, 2009. p. 1–8.
[24] Pang C, Dutta P, Kim S, Kezunovic M, Damnjanovic I. PHEVs as dynamically configurable dispersed energy storage for V2B uses in the smart grid. In: Proceedings of the IEEE conference on power generation, transmission, distribution and energy conversion, 2010. p. 1–6.

[25] Hutson C, Venayagamoorthy GK, Corzine KA. Intelligent scheduling of hybrid and electric vehicle storage capacity in a parking lot for profit maximization in grid power transactions. In: Proceedings of the IEEE conference on energy 2030, 2008. p. 1–8.
[26] Accenture News. Changing the game: plug-in electric vehicle pilots, ⟨http://newsroom.accenture.com/article_display.cfm?article_id=5151⟩; 2011.
[27] Pillai JR, Bak-Jensen B. Integration of vehicle-to-grid in the western Danish power system. IEEE Trans Sustain Energy 2011;2(1):12–9.
[28] Saber AY, Venayagamoorthy GK. Plug-in vehicles and renewable energy sources for cost and emission reductions. IEEE Trans Ind Electron 2011;58 (4):1229–38.
[29] Jansen B, Binding C, Sundström O, Gantenbein D. Architecture and communication of an electric vehicle virtual power plant. In: Proceedings of the IEEE national conference on smart grid communication, 2010. p. 149–54.
[30] Kessels JTBA, van den Bosch PPJ. Plug-in hybrid electric vehicles in dynamical energy markets. In: Proceedings of the IEEE conference on intelligent vehicles, 2008. p. 1003–8.
[31] Khodayar ME, Wu L, Shahidepour M. Hourly coordination of electric vehicle operation and volatile wind power generation in SCUC. IEEE Trans Smart Grid 2012;3(3):1271–9.
[32] Lan T, Kang Q, An J, Yan W, Wang L. Sitting and sizing of aggregator controlled park for plug-in hybrid electric vehicle based on particle swarm optimization. Neural Comput Appl 2011. http://dx.doi.org/10.1007/s00521-011-0687-2.
[33] Peças Lopes JA, Rocha Almeida PM, Soares FJ. Using vehicle-to-grid to maximize the integration of intermittent renewable energy resources in islanded electric grids. In: Proceedings of the IEEE conference on clean electrical power, 2009. p. 290–5.
[34] Marano V, Rizzoni G. Energy and economic evaluation of PHEVs and their interaction with renewable energy sources and the power grid. In: Proceedings of the IEEE conference on vehicular electronics and safety, 2008. p. 84–9.
[35] Kadurek P, Ioakimidis C, a Ferrao P. Electric vehicles and their impact to the electric grid in isolated systems. In: Proceedings of the IEEE conference on power engineering, energy and electrical drives, 2009. p. 49–54.
[36] Zhou X, Wang G, Lukic S, Bhattacharya S, Huang A. Multi-function bi-directional battery charger for plug-in hybrid electric vehicle application. In: Proceedings of the IEEE conference on energy conversion congress and exposition (ECCE), 2009. p. 3930–6.
[37] Gu Y, Xie L. Look-ahead coordination of wind energy and electric vehicles: a market-based approach. In: Proceedings of the IEEE North American power symposium (NAPS), 2010. p. 1–8.
[38] Sortomme E, El-Sharkawi MA. Optimal combined bidding of vehicle-to-grid ancillary services. IEEE Trans Smart Grid 2012;3(1):70–9.
[39] Ota Y, Taniguchi H, Nakajima T, Liyanage KM, Yokoyama A. Autonomous distributed V2G (vehicle-to-grid) considering charging request and battery condition. In: Proceedings of the IEEE conference on innovative smart grid technologies, 2010. p. 1–6.
[40] Sortomme E, El-Sharkawi MA. Optimal scheduling of vehicle-to-grid energy and ancillary services. IEEE Trans Smart Grid 2012;3(1):351–9.
[41] Turton H, Moura F. Vehicle-to-grid systems for sustainable development: an integrated energy analysis. Technol Forecast Soc Change 2008;75:1091–108.
[42] Beer S, Gomez T, Dallinger D, Momber I, Marnay C, Stadler M, et al. An economic analysis of used electric vehicle batteries integrated into commercial building microgrids. IEEE Trans Smart Grid 2012;3(1):517–25.
[43] Qiu Y, Liu H, Wang D, Liu X. Intelligent strategy on coordinated charging of PHEV with TOU price. In: Proceedings of the IEEE power and energy engineering conference (APPEEC), 2011. p. 1–5.
[44] Wang S, Han L, Wang D, Shahidehpour M, Li Z. Hierarchical charging management strategy of plug-in hybrid electric vehicles to provide regulation service, In: Proceedings of the IEEE PES international conference and exhibition on innovative smart grid technologies (ISGT Europe), 2012. p. 1–6.
[45] Dyke KJ, Schofield N, Barnes M. The impact of transport electrification on electrical networks. IEEE Trans Ind Electron 2010;57(12):3917–26.
[46] Han Sekyung, Han Soohee, Sezaki K. Development of an optimal vehicle-to-grid aggregator for frequency regulation. IEEE Trans Smart Grid 2010;1 (1):65–72.
[47] Sortomme E, El-Sharkawi MA. Intelligent dispatch of electric vehicles performing vehicle-to-grid regulation. In: Proceedings of the IEEE international conference on electric vehicle, 2012. p. 1–6.
[48] U.S. Environmental Protection Agency (EPA). Technical highlights: plug-in hybrid electric vehicles, ⟨http://www.epa.gov/otaq/climate/420f07048.pdf⟩; October 2007.
[49] U.S. Environmental Protection Agency (EPA). Greenhouse gas reporting program: 2010 data publication,⟨http://epa.gov/climatechange/emissions/ghgdata/2010data.html⟩; January 2012.
[50] Vlachogiannis JG. Probabilistic constrained load flow considering integration of wind power generation and electric vehicles. IEEE Trans Power Syst 2009;24(4):1808–17.
[51] Yu D, Liu Yanhua, Li J, Liu Yaohui. The potential benefit of controlled PEV charging on the wind power integration. In: Proceedings of the IEEE conference on power system technology, (POWERCON) 1–5, 2010.
[52] Liu Y, Yu D. The regional wind power fluctuation in China and potential accommodation by PEV charging. In: Proceedings of the IEEE conference on IPEC, 2010. p. 717–21.
[53] Li X, Lopes LAC, Williamson SS. On the suitability of plug-in hybrid electric vehicle (PHEV) charging infrastructures based on wind and solar energy. In: Proceedings of the IEEE Power and Energy Society general meet, 2009. p, 1–8.